5. POTENTIAL FOR HUMAN EXPOSURE

5.1 OVERVIEW

Most of the naphthalene entering the environment is discharged to the air. The largest releases result from the combustion of wood and fossil fuels and the off-gassing of naphthalene-containing moth repellents" Smaller amounts of naphthalene are introduced to the water as the result of discharges from coal tar production and distillation processes. The coal tar industry is also a major source of the small amounts of naphthalene that are directly discharged to land.

Naphthalene in the atmosphere is subject to a number of degradation processes including reaction with photochemically produced hydroxyl radicals. Naphthalene has a short half-life in most natural waters and soils because of its tendency to volatilize and biodegrade. As a consequence of these processes, there is little tendency for naphthalene to build up in the environment over time.

The concentration of naphthalene in air tends to be low in rural areas, but is elevated in urban areas. The highest atmospheric concentrations have been found in the immediate vicinity of specific industrial sources and hazardous waste sites. Naphthalene is also a common indoor contaminant in households using naphthalene-containing moth repellents or where tobacco is smoked. Sidestream smoke from one cigarette contained 46, 30, and 32 μg of naphthalene, l-methylnaphthalene, and 2-methylnaphthalene, respectively. Levels in water, sediments, and soil tend to be low, except in the immediate vicinity of point sources of release, such as chemical waste sites.

The most likely pathway by which the general public is exposed to naphthalene is by inhalation due to the release of this substance from combustion fuels, moth repellents, and cigarette smoke. The estimated average per capita daily intake from ambient air is 19 μg. Exposure by other routes is not likely.

High naphthalene exposure levels could occur near industrial sources or chemical waste sites, but the extent of such exposure to individuals can only be evaluated on a site-by-site basis. The same situation could occur in certain work environments including naphthalene-producing industries and

naphthalene-using industries such as wood preserving, tanning, coal distillation, and ink and dye production.

Based on limited data, potential human exposure to 1-methylnaphthalene or 2-methylnaphthalene is expected to be mainly by inhalation from ambient air. Exposure to these chemicals from tobacco smoke is likely.

The information regarding the release and fate of 1-methylnaphthalene and 2-methylnaphthalene indicates that these chemicals are also present in the environment, particularly in air, and are released from many of the same natural and industrial sources as naphthalene (combustion of wood and fossil fuels, tobacco smoke, coal distillation), but in smaller quantities.

Naphthalene has been identified in at least 536 of the 1,408 hazardous waste sites that have been proposed for inclusion on the EPA National Priorities List (NPL) (HAZDAT 1994). l-Methylnaphthalene has been identified in at least 31 of these sites, and 2-methylnaphthalene has been identified in at least 328 of these sites. However, the number of sites evaluated for these chemicals is not known. The frequency of the sites at which naphthalene, 1-methylnaphthalene, and 2-methylnaphthalene have been identified within the United States can be seen in Figures 5-l through 5-3.

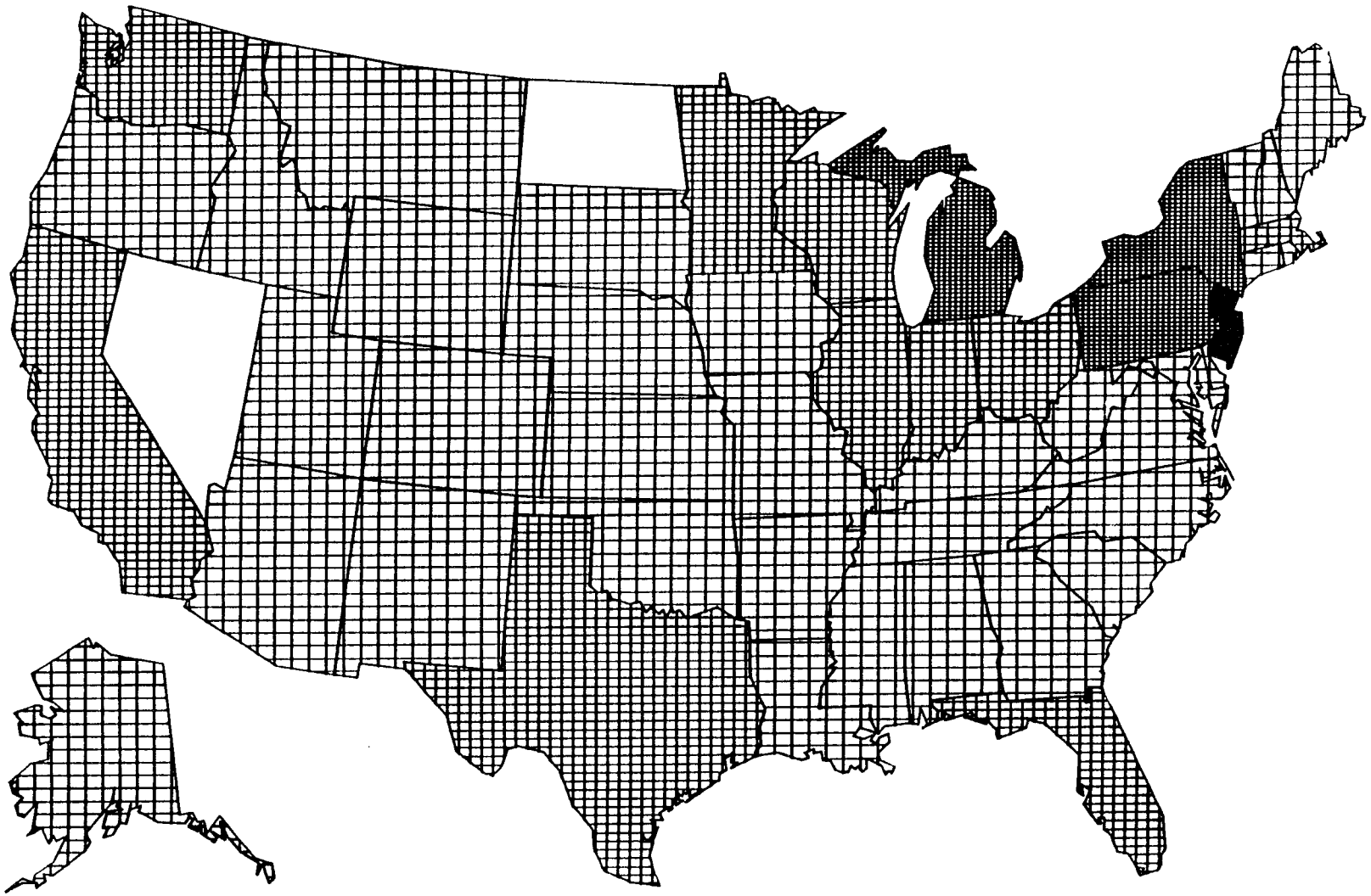
5.2 RELEASES TO THE ENVIRONMENT

Most of the naphthalene entering environmental media is from combustion, mainly residential wood heating, or from the use of naphthalene in moth repellents. About 10% of environmental releases are attributable to coal production and distillation, while naphthalene production losses contribute less than 1% of environmental releases (Coons et al. 1982). Methylnaphthalenes are released from similar sources, including fuel combustion and industrial discharges (GDCH 1992). Smoking tobacco also releases small amounts of naphthalene and methylnaphthalenes into the environment.

5.2.1 Air

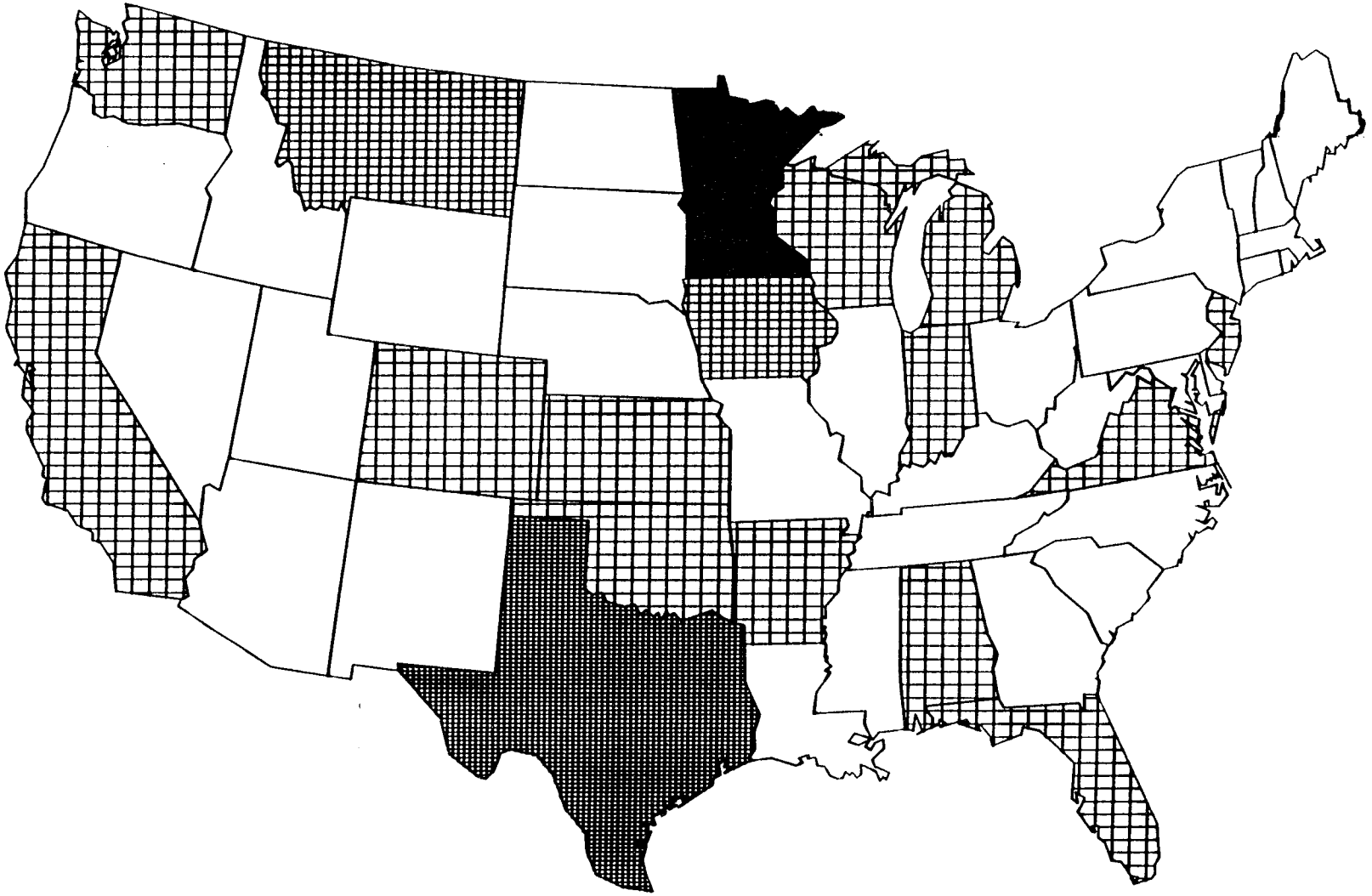
Nearly all naphthalene entering the environment is released directly to the air (92.2%). The largest source of emission (more than 50%) is through inadvertent releases due to residential combustion of

FIGURE 5-1. FREQUENCY OF NPL SITES WITH NAPHTHALENE CONTAMINATION *



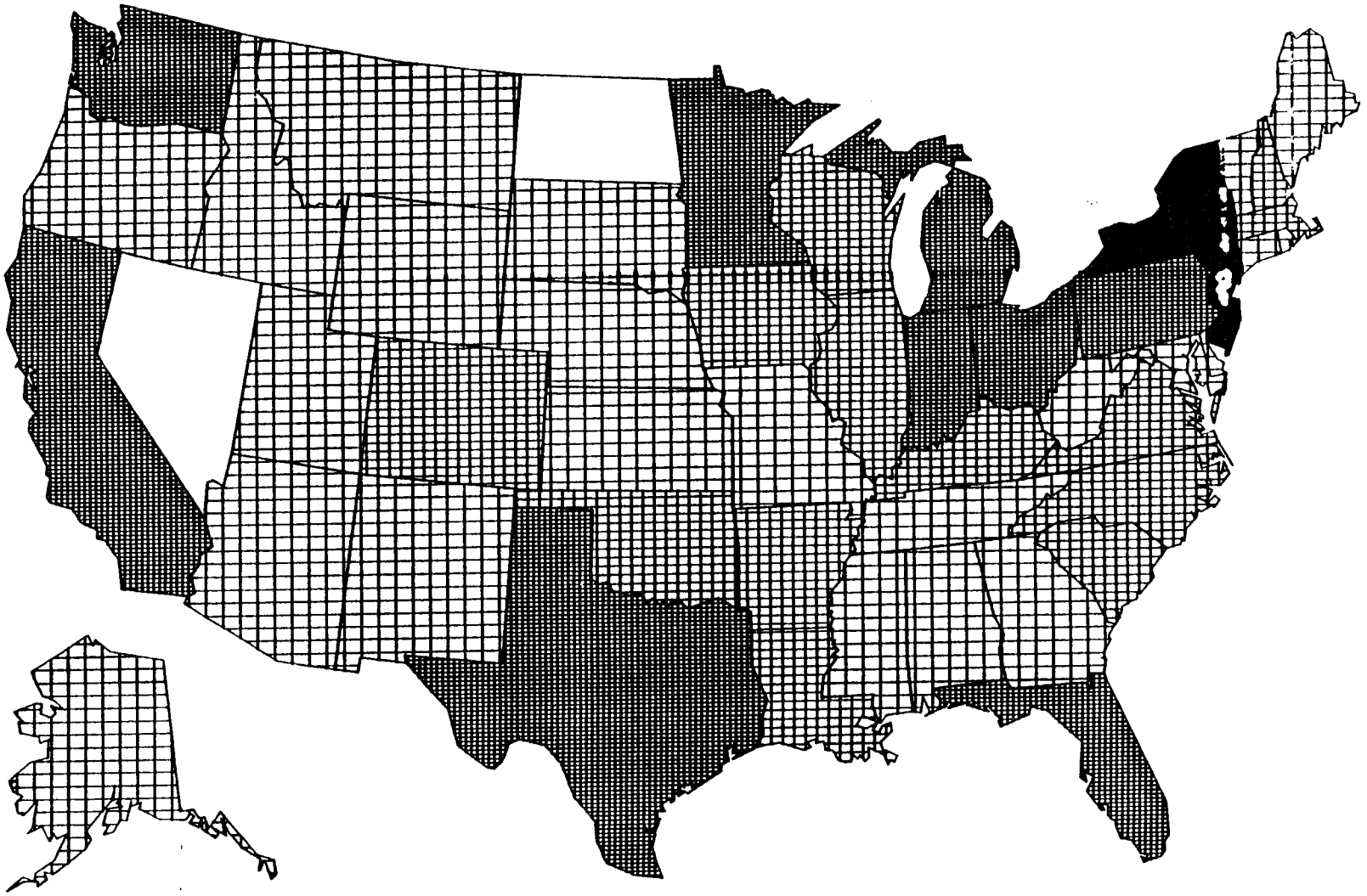
*Derived from HazDat 1994

FIGURE 5-2. FREQUENCY OF NPL SITES WITH 1-METHYLNAPHTHALENE CONTAMINATION *



*Derived from HazDat 1994

FIGURE 5-3. FREQUENCY OF NPL SITES WITH 2-METHYLNAPHTHALENE CONTAMINATION *



*Derived from HazDat 1994

wood and fossil fuels (Coons et al. 1982). Naphthalene emissions from unvented kerosene space heaters have been reported (Traynor et al. 1990).

The second greatest contribution comes from the use of naphthalene as a moth repellent (Coons et al. 1982). Because it volatilizes appreciably at room temperature, virtually all the naphthalene contained in moth repellent is emitted to the atmosphere. Thus, in 1989, about 12 million pounds of naphthalene were released to air from moth repellent use (see Section 4.3).

Naphthalene may also enter the atmosphere during coal tar production and distillation processes, through volatilization processes (aeration) in publicly owned treatment works (POTWs), from the use of naphthalene in the manufacture of phthalic anhydride, during the production of naphthalene, and from tobacco smoke. Methylnaphthalenes may be released to air in stack emissions and from fuel combustion, forest fires, and tobacco smoke (GDCH 1992; HSDB 1995; IARC 1993). l-Methyl-naphthalene and 2-methylnaphthalene were reported in jet exhaust at average concentrations of 421 μg/m^3 and 430 μg/m^3, respectively, and in the gas phase of diesel motor exhaust at 1.57 μg/m^3 each (GDCH 1992). The smoke of an American unfiltered cigarette contains 2.8 μg of naphthalene, 1.2 μg of l-methylnaphthalene, and 1.0 μg of 2-methylnaphthalene. Smoke from an equivalently filtered “little cigar” contains 1.2 μg of naphthalene, 0.9 μg of 1-methylnaphthalene, and 0.7 μg of 2-methylnaphthalene (Schmeltz et al. 1976).

As shown in Table 5-1, an estimated total of 2.6 million pounds of naphthalene, amounting to about 59% of the total environmental release, was discharged to the air from manufacturing and processing facilities in the United States in 1992 (TR192 1994). The TRI data should be used with caution since only certain types of facilities are required to report. This is not an exhaustive list.

5.2.2 Water

About 5% of all naphthalene entering the environment is released to water (Coons et al. 1982). Most of that amount is attributable to coal tar production and distillation processes. Some naphthalene (about 60%) from these sources is discharged directly to surface waters; the remainder is distributed to POTWs. The only other contributions of any consequence enter the nation’s waterways from wood preserving industry effluent and from oil spills.

Naphthalene was detectable in 1.6% of effluent samples reported on the STORET database from 1980 to 1982 (Staples et al. 1985). Analysis of STORET data for 1978-1981 indicated the range of detectable naphthalene concentrations in effluents was <l-36,000 μg/L (Coons et al. 1982).

The detection of naphthalene and methylnaphthalenes in groundwater in the vicinity of industrial facilities and landfills (see Section 5.4.2) (Brown and Donnelly 1988; Rosenfeld and Plumb 1991) indicates that these chemicals are released to water from these sources. Methylnaphthalenes have been detected in effluents from industrial sources (GDCH 1992; HSDB 1995). l-Methylnaphthalene and 2-methylnaphthalene were reported in process sewage and production water samples from coal gasification plants at concentrations ranging from 78 to 278 μg/L and 66-960 μg/L, respectively (GDCH 1992).

As shown in Table 5-1, an estimated total of 29,000 pounds of naphthalene, amounting to about 0.7% of the total environmental release, was discharged to surface water from manufacturing and processing facilities in the United States in 1992 (TR192 1994). An additional 78,000 pounds (1.8% of the total) was discharged to underground injection. The TRI data should be used with caution since only certain types of facilities are required to report.

5.2.3 Soil

It is estimated that only about 2.7% of the environmental releases of naphthalene are discharged to land (Coons et al. 1982). Sources include coal tar production and minor contributions from naphthalene production, POTW sludge disposal, and the use of organic chemicals that include naphthalene.

As shown in Table 5-1, an estimated 1.7 million pounds of naphthalene, amounting to about 39% of the total environmental release, was discharged to land from manufacturing and processing facilities producing and using naphthalene in the United States in 1992 (TR192 1994). The TRI data should be used with caution since only certain types of facilities are required to report.

No information was located on releases of 1-methylnaphthalene or 2-methylnaphthalene to soil.

Table 5-1. Releases to the Environment from Facilities That Manufacture or Process Napthalene

State[b]	Number of facilities	Range of reported amounts released in pounds per year[a]						
		Air	Water	Land	Underground injection	Total environment[c]	POTW transfer	Off-site waste transfer
AK	1	1067	0	0	0	1067	0	0
AL	18	0-54000	0-750	0-10500	0	0-54005	0-50000	0-135000
AR	3	5-250	0	0	0	5-250	0	0-5
AZ	2	1200-1800	0	0	0	1200-1800	0	0
CA	39	0-8280	0-85	0-200	0	0-8280	0-1359	0-16485
CO	1	3310	8	0	0	3318	0	33
CT	2	410-690	0-24	0	0	434-690	0	4657-11835
DE	1	15100	520	87	0	15707	0	2700
FL	4	0-1500	0	0	0	0-1500	0	0-250
GA	13	0-46262	0-1954	0-3610	0	0-46262	0-5	0-7484
HI	2	250-3350	0	0	0	250-3350	0	0
IA	6	384-81259	0	0	0	384-81259	0	0-138160
IL	33	0-58150	0-41	0-8	0	0-58150	0-3419	0-63539
IN	17	0-40990	0	0-48	0-17000	0-53750	0-88	0-44564
KS	6	0-16000	0	0	0	0-16000	0	0-328
KY	16	0-26250	0-710	0-250	0	0-26750	0-750	0-86000
LA	27	0-52160	0-290	0-47	0-16	0-52181	0	0-374185
MA	1	0	0	0	0	0	0	19411
MD	2	3-5	0	0	0	3-5	0	0
MI	13	1-85000	0	0-85000	0	1-170000	0-5	0-27560
MN	3	255-14504	0-62	0	0	255-14566	0	0-3700
MO	8	10-72784	0-5	0-6471	0	10-72784	0-45	0-32004
MS	10	5-42600	0-250	0-250	0	5-42600	0-5	0-6520
MT	3	500-2570	0-7	0-30	0	500-2602	0	0-957
NC	6	0-15468	0	0	0	0-15468	0-250	0-3623
ND	2	2020-9583	0	0	0	2020-9583	0	250-532
NE	3	0-87750	0	0	0	0-87750	0-19100	0-5135
NJ	19	0-5826	0-257	0-776	0	0-5826	0-38	0-13180
NM	1	500	0	0	0	500	5	255
NY	3	0-6900	0	0	0	0-6900	0	0
OH	34	0-63600	0-250	0-1200	0	0-64830	0-250	0-141365
OK	6	0-15000	0-44	0-3400	0	1-15000	0	0-5300
PA	27	0-26400	0-250	0-35	0	0-26400	0-250	0-192910
PR	4	3-255	0	0	0	3-255	0	0
SC	7	0-8980	0-6730	0-3635	0	0-19345	0-5	0-5

Table 5-1. Releases to the Environment from Facilities That Manufacture or Process Napthalene(continued)

		Range of reported amounts released in pounds per year[a]						
State[b]	Number of facilities	Air	Water	Land	Underground injection	Total environment[c]	POTW transfer	Off-site waste transfer
SD	1	122	0	0	0	122	0	0
TN	9	0-18356	0-9	0	0	0-18356	0-7150	0-2250
TX	77	0-180000	0-3900	0-1531000	0-59000	0-1608010	0-1300	0-651313
UT	7	2-6872	0	0	0	2-6872	0-90	0-250
VA	5	39-10135	0	0	0	39-10135	0	0-7485
VI	2	6-13950	0-67	0	0	6-14017	0	0
WA	8	9-9078	0-500	0-250	0	9-9078	0	0-23100
WI	4	500-27000	0-250	0-1200	0	500-27250	0-250	0-750
WV	7	10-28500	0-266	0-5138	0	10-28500	0	0-16000
WY	4	49-4776	0	0-10	0	49-4786	0	0-307

Source: TRI92 1994

[a] Data in TRI are maximum amounts released by each facility.
[b] Post office state abbreviations used
[c] The sum of all releases of the chemical to air, land, water, and underground injection wells by a given facility

POTW = publicly owned treatment works

5.3 ENVIRONMENTAL FATE

5.3.1 Transport and Partitioning

Naphthalene released to the atmosphere may be transported to surface water and/or soil by wet or dry deposition Since most airborne naphthalene is in the vapor phase, deposition is expected to be very slow (about 0.04-0.06 cm/sec). It has been estimated that about 2-3% of naphthalene emitted to air is transported to other environmental media, mostly by dry deposition (Coons et al. 1982).

Naphthalene in surface water may volatilize to the atmosphere. With a vapor pressure of 0.087 mmHg at 25°C solubility in water of 31.7 mg/L at 20°C and a Henry's law constant of $4.6x10^{-4}$ (Mabey et al. 1982), it is likely that volatilization will be an important route of naphthalene movement from water. The rate of volatilization also depends upon several environmental conditions, including temperature, wind velocity, and mixing rates of the air and water columns (Coons et al. 1982). The half-life of naphthalene in the Rhine River was 2.3 days, based on monitoring data (Zoeteman et al. 1980). In a mesocosm experiment which simulated Narragansett Bay, the half-life in water was 12 days during winter, with loss primarily due to volatilization (Wakeham et al. 1983).

Log octanol/water partition coefficients (K_{ow}) for naphthalene range from 3.29 to 3.37 and log organic carbon coefficients (K_{oc}) range from 2.97 to 3.27 (Bahnick and Doucette 1988; Howard 1989; Klecka et al. 1990; Mabey et al. 1982; Thomann and Mueller 1987). These include both experimentally determined and calculated values. The reported experimentally determined log K_{oc} is 3.11 (Bahnick and Doucette 1988). Based on the magnitude of these values, it is expected that only a small fraction (less than 10%) of naphthalene in typical surface water would be associated with particulate matter (Thomann and Mueller 1987). Thus, naphthalene discharged to surface waters would remain largely in solution, with smaller quantities being associated with suspended solids and benthic sediments.

Naphthalene is easily volatilized from aerated soils (Park et al. 1990) and is adsorbed to a moderate extent (10%) (Karickhoff 1981; Schwarzenbach and Westall 1981). The extent of sorption depends on the organic carbon content of the soil, with rapid movement expected through sandy soils (Howard 1989). The estimated soil adsorption coefficient for naphthalene in a soil with less than 0.6% organic carbon is 1.8 (Klecka et al. 1990). Because it adsorbs to aquifer material (Ehrlich et al. 1982),

naphthalene's passage through groundwater will be somewhat retarded. Nevertheless, naphthalene frequently appears in effluent drainage from disposal sites (Rittman et al. 1980; Roberts et al. 1980; Schwarzenbach et al. 1983). However, sorption of naphthalene to aquifer materials with low organic carbon content (<0.03%) may be enhanced by the presence of nonionic low-polarity organics, such as tetrachloroethene, commonly found at hazardous waste sites (Brusseau 1991a)"

Bioconcentration factors (BCFs) for naphthalene have been measured and calculated from the K_{ow}, K_{oc}, or water solubility. The values reported for log BCF range from 1.6 to 3 (Banerjee and Baughman 1991; Bysshe 1982; Geyer et al. 1982; Kenaga 1980; Southworth et al. 1978; Veith et al. 1979), indicating moderate bioconcentration in aquatic organisms. Naphthalene is reported to be rapidly eliminated from invertebrates when the organisms are placed in pollutant-free water (Eastmond et al. 1984; Tarshis 1981) and naphthalene is readily metabolized in fish (Howard 1989). Based on the magnitude of the K_{ow}, bioaccumulation in the food chain is not expected to occur (Thomann 1989). However, naphthalene exposure of cows and chickens could lead to the presence of naphthalene in milk and eggs (Eisele 1985).

Limited data were located on transport and partitioning of methylnaphthalenes in the environment. The vapor pressures (0.054 and 0.068 mmHg), water solubilities (25.8 and 24.6 mg/L), and Henry's law constants ($3.60x10^{-4}$ and $4.99x10^{-4}$ atm-m^3/mol) for 1-methylnaphthalene and 2-methylnaphthalene are of similar magnitude to these properties for naphthalene (HSDB 1995; Yaws et al. 1991). Thus, it is likely that loss of methylnaphthalenes from ambient water occurs by volatilization. In a mesocosm experiment which simulated Narragansett Bay, the half-life of 2-methylnaphthalene in water was 13 days in winter, with loss primarily due to volatilization (Wakeham et al. 1983). Based on the magnitude of log K_{ow} for 1-methylnaphthalene and 2-methylnaphthalene (3.87 and 3.86, respectively) (HSDB 1995) and the experimental log K_{oc} for 2-methylnaphthalene (3.93) (Bahnick and Doucette 1988) these chemicals may partition similarly to naphthalene in environmental media and are expected to be slightly mobile to immobile in soils (HSDB 1995). Log BCFs calculated for 2-methylnaphthalene range from 2 to 2.8 (Kenaga 1980) and measured lag BCFs for 1-methylnaphthalene and 2-methylnaphthalene in oysters ranged from 2.7 to 4.1 (GDCH 1992). Methylnaphthalenes are also metabolized and excreted rapidly by fish and shellfish when they are removed from polluted waters (Breger et al. 1984; GDCH 1992).

5.3.2 Transformation and Degradation

5.3.2.1 Air

The most important atmospheric removal process for naphthalene is reaction with photochemically produced hydroxyl radicals (Howard 1989). The rate for this reaction is 2.17×10^{-11} cm^3/molecule-sec (Atkinson et al. 1987) and the atmospheric half-life for naphthalene based on this reaction is less than 1 day. The major products of this reaction are 1- and 2-naphthol and l- and 2-nitronaphthalene (Atkinson et al. 1987). Naphthalene also reacts with N_2O_5, nitrate radicals, and ozone in the atmosphere (Atkinson et al. 1984, 1987) and photolysis is expected to occur, although no experimental data were located (Howard 1989).

Methylnaphthalenes also react with hydroxyl radicals. The reported rate constants are 5.30×10^{-11} and 5.23×10^{-11} cm^3/molecule-sec for 1-methylnaphthalene and 2-methylnaphthalene, respectively. Based on an atmospheric OH concentration of $lx10^6/cm^3$, the corresponding atmospheric half-lives are 3.6 and 3.7 hours (GDCH 1992). Reactions of 1-methylnaphthalene and 2-methylnaphthalene with N_2O_5 radicals have half-lives of 24 and 19 days, respectively (GDCH 1992). These chemicals also react with atmospheric ozone.

5.3.2.2 Water

Naphthalene and methylnaphthalenes are degraded in water by photolysis and biological processes. The half-life for photolysis of naphthalene in surface water is estimated to be about 71 hours, but the half-life in deeper water (5 m) is estimated at 550 days (Zepp and Schlotzhauer 1979). The half-lives for photolysis of 1-methylnaphthalene and 2-methylnaphthalene were estimated at 22 and 54 hours, respectively (GDCH 1992).

Biodegradation of naphthalene is sufficiently rapid for it to be a dominant fate process in aquatic systems (Tabak et al. 1981). Data on biodegradation of naphthalene in biodegradability tests and natural systems suggest that biodegradation occurs after a relatively short period of acclimation (rapidly [half-life about 7 days] in oil-polluted water, slowly [half-lives up to 1,700 days] in unpolluted water), and that the biodegradation rate increases with the naphthalene concentration (Herbes 1981; Herbes and Schwa11 1978; Herbes et al. 1980; Howard 1989; Kappeler and Wuhrmann

1978). Reported biodegradation half-lives range from 3 to 1,700 days in various water systems (Howard 1989). In a static-flask-screening test, naphthalene showed rapid acclimation and 100% loss from the test medium in 7 days (Tabak et al. 1981). In an experiment with Narragansett Bay seawater, the half-life of naphthalene in late summer was reported at 0.8 days, mainly due to biodegradation (Wakeham et al. 1983). The half-life of 2-methylnaphthalene was 0.7 days in the same experiment.

Methylnaphthalenes are biodegraded under aerobic conditions after adaptation. The highest degradation rates were reported in water constantly polluted with petroleum (GDCH 1992).

5.3.2.3 Sediment and Soil

Naphthalene biodegradation rates are about 8-20 times higher in sediment than in the water column above the sediment (Herbes and Schwa11 1978). Half-lives reported in sediment include 4.9 hours and more than 88 days in oil-contaminated and uncontaminated sediment, respectively (Herbes and Schwall 1978), 9 days in sediment near a coal coking discharge (Herbes 1981), 3, 5, and more than 2,000 hours in sediments with high, medium, and low PAH levels, respectively (Herbes et al. 1980), and ranging from 2.4 weeks in sediments exposed to petroleum hydrocarbons to 4.4 weeks in sediments from a pristine environment (Howard 1989). Methylnaphthalenes biodegrade more slowly. Reported half-lives in sediments were 46 weeks for 1-methylnaphthalene and ranged from 14 to 50 weeks for 2-methylnaphthalene (GDCH 1992).

In soils, biodegradation potential is important to biological soil remediation. Studies on biodegradation of PAHs suggest that adsorption to the organic matter significantly reduces the bioavailability, and thus the biodegradability, of PAHs, including naphthalene (Heitzer et al. 1992; Weissenfels et al. 1992). There is considerable variability in reported naphthalene soil half-lives. The estimated half-life of naphthalene reported for a solid waste site was 3.6 months (Howard 1989). In typical soils, more rapid biodegradation is expected to occur (Howard 1989). In soils with 0.2-0.6% organic carbon and 92-94% sand, the half-lives were 11-18 days (Klecka et al. 1990). In another study, sandy loams with 0.5-l% organic carbon had naphthalene half-lives of 2-3 days (Park et al. 1990). Biodegradation is accomplished through the action of aerobic microorganisms and declines precipitously when soil conditions become anaerobic (Klecka et al. 1990). Studies indicate that naphthalene biodegrades to carbon dioxide in aerobic soils, with salicylate as an intermediate product (Heitzer et al. 1992).

Abiotic degradation of naphthalene seldom occurs in soils. In one study only about 10% of the naphthalene added to two soil samples treated with mercuric chloride to kill microorganisms was degraded over a 105- or 196-day period (Park et al. 1990).

The behavior of 1-methylnaphthalene in sandy loam was very similar to that of naphthalene. l-Methylnaphthalene was easily volatilized from aerated soil, and the biodegradation half-life averaged between 1.7 and 2.2 days (Park et al. 1990). No data were identified on the biodegradation of 2-methylnaphthalene in soil.

5.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

5.4.1 Air

Naphthalene has been reported in ambient air at several locations in the United States. The average reported concentration for 67 samples was 0.991 ppb (5.19 μg/m^3), with most (60) of the samples and the highest concentrations at source-dominated locations (Shah and Heyerdahl 1988). A median naphthalene level in urban air in 11 U.S. cities of 0.18 ppb (0.94 μg/m^3) has been reported (Howard 1989). An average naphthalene concentration of 170 μg/m^3 in outdoor air was reported in a residential area of Columbus, Ohio (Chuang et al. 1991) and naphthalene was measured in ambient air in Torrance, California at a concentration of 3.3 μg/m^3 (Propper 1988). Average naphthalene concentrations detected in ambient air at five hazardous waste sites and one landfill in New Jersey ranged from 0.08 to 0.88 ppb (0.42 to 4.6 μg/m^3) (La Regina et al. 1986).

Naphthalene concentrations in indoor air may be higher than outdoors, with reported average indoor concentrations in various areas of homes ranging from 0.860 to 1,600 μg/m^3 (Chuang et al. 1991; Hung et al. 1992; Wilson et al. 1989). However, based on a careful analysis of Chuang et al. (1991) , the reported upper range value may be in error. A more representative upper limit concentration for indoor air may be 32 μg/m^3 (6 ppb), recorded in buildings from heavily trafficked urban areas of Taiwan (Hung et al. 1992). In homes with smokers, indoor and outdoor air concentrations measured by using filtered and sorbent extracts were 2.2 μg/m^3 and 0.3 μg/m^3, respectively. Comparable values in homes without smokers were 1.0 μg/m^3 and 0.1 μg/m^3, respectively (Gold et al. 1991; IARC 1993). The average reported concentration of naphthalene inside automobiles in commuter traffic is about 4.5 μg/m^3 (Lofgren et al. 1991).

Naphthalene has also been detected in air in industrial facilities. Reported naphthalene vapor levels ranged from 11 to 1,100 ug/m3 in a coke plant and from 0.72 to 310 μg/m^3 in an aluminum reduction plant (Bjorseth et al. 1978a, 1978b). Reported particulate levels for the same facilities ranged from nondetected to 4.4 μg/m^3, and 0.9 to 4 μg/m^3, respectively.

1-methylnaphthalene and 2-methylnaphthalene have been reported in ambient air at average concentrations of 0.086 and 0.011 ppb (0.51 and 0.065 μg/m^3), respectively (Shah and Heyerdahl 1988). Most of the data reported are from source-dominated areas where the highest concentrations were detected. Methylnaphthalene (isomer not specified) was detected (concentration not reported) in ambient air at a hazardous waste site in New Jersey (La Regina et al. 1986). 2-Methylnaphthalene was also reported in indoor air at an average concentration of 0.252 ppb (1.5 μg/m^3) (Shah and Heyerdahl 1988).

5.4.2 Water

Naphthalene has been detected in surface water and groundwater in the United States. An analysis of 1980-1982 data from the STORET database indicates that naphthalene was detectable in 7% of 630 ambient water samples (Staples et al. 1985). The median concentration for all samples was less than 10 μg/L. Analysis of earlier (1978-1980) STORET data for naphthalene showed concentrations in positive samples ranging from 0.005 to 17 μg/L (Coons et al. 1982). Naphthalene was also detected in 11% of 86 urban runoff samples at concentrations ranging from 0.8 to 2.3 μg/L (Cole et al. 1984).

Naphthalene is rarely detected in drinking water. Naphthalene was reported in drinking water supplies in one area in the United States at levels up to 1.4 μg/L (Coons et al. 1982).

Naphthalene and 2-methylnaphthalene were detected in groundwater at five wood treatment facilities (Rosenfeld and Plumb 1991). Naphthalene was reported in 35% of samples at all five sites at an average concentration of 3,312 μg/L. 2-Methylnaphthalene was reported in 27% of samples at four sites at an average concentration of 563 μg/L. Naphthalene was reported in leachate or groundwater plume from industrial and municipal landfills at concentrations ranging from less than 10 to 18.69 mg/L and 0.110 to 19 mg/L, respectively. Methylnaphthalene (isomer not specified) concentration reported at a municipal landfill was 0.033 mg/L (Brown and Donnelly 1988).

1-methylnaphthalene and 2-methylnaphthalene were reported in an urban snowpack in Michigan at concentrations ranging from less than 0.05 to 0.177 μg/L and less than 0.05 to 0.251 μg/Lg respectively (Boom and Marsalek 1988).

Naphthalene has been reported at a mean concentration of 6.3 ng/L in seawater in the south Atlantic Ocean (Cripps 1992).

5.4.3 Sediment and Soil

Naphthalene and methylnaphthalenes have been reported at low concentrations in uncontaminated soils and sediments and at higher concentrations near sources of contamination. Naphthalene has been reported in untreated agricultural soils at levels ranging from 0 to 3 μg/kg (Wild et al. 1990). Reported naphthalene concentrations in contaminated soils included 6.1 μg/g in coal tar contaminated soil (Yu et al. 1990), 16.7 mg/kg in soil from a former tar-oil refinery (Weissenfels et al. 1992) and up to 66 μg/kg in sludge-treated soils (Wild et al. 1990). Methylnaphthalenes (isomer not specified) were reported at a concentration of 2.9 μg/g in coal tar contaminated soil (Yu et al. 1990).

Naphthalene was reported as detectable in 7% of 267 sediment samples entered into the STORET database (1980-1982), with the median concentration for all samples less than 500 μg/kg (Staples et al. 1985). Another analysis of STORET data indicated that concentrations in positive sediment samples ranged from 0.02 to 496 μg/kg (Coons et al. 1982). Naphthalene and methylnaphthalenes (isomers not specified) were detected in contaminated and noncontaminated estuarine sediments (Brooks et al. 1990). Reported average concentrations were 54.7 and 61.9 ppb μg/kg) naphthalene and 50.4 and 55.3 ppb (μg/kg) methylnaphthalenes at 10 and 25 miles from an offshore coastal multiwell drilling platform. Naphthalene and methylnaphthalenes concentrations in nearby noncontaminated estuarine sediments were 2.1 and 1.9 ppb (μg/kg), respectively.

5.4.4 Other Environmental Media

Naphthalene is not generally reported in fish, but has been detected in shellfish in the United States. Naphthalene was not detected in 83 biota samples (median detection limit 2.5 mg/kg) reported from 1980-1982 in ng/g in oysters, from 4 to 10 ng/g in mussels, and from less than 1 to 10 ng/g in clams

from United States waters (Bender and Huggett 1989). Methylnaphthalenes have occasionally been detected in fish from polluted waters. 2-Methylnaphthalene was reported at concentrations ranging from 0.4 to 320 μg/g in fish from Ohio waters, but neither methylnaphthalene was detected in muscle tissue of fish from polluted areas of Puget Sound (GDCH 1992). Methylnaphthalenes were also detected in oysters in Australia at <0.3-2 μg/g.

Naphthalene has been detected very infrequently in food products in the United States. Naphthalene was detected in 2 of 13,980 samples of foods analyzed in six states (Minyard and Roberts 1991).

No information was located that documented methylnaphthalenes in food products.

Reported levels of naphthalene, l-methylnaphthalene, and 2-methylnaphthalene in smoke from one US. commercial unfiltered cigarette were 3 μg, 1 μg, and 1 μg, respectively (Schmeltz et al. 1978). Levels in sidestream smoke were higher; 46, 30, and 32 μg/cigarette for these three chemicals, respectively (Schmeltz et al. 1976).

Naphthalene has been detected in ash from municipal refuse and hazardous waste incinerators (Carroll and Oberacker 1989; Shane et al. 1990). Naphthalene was detected in seven of eight municipal refuse ash samples at 6-28,000 μg/kg (Shane et al. 1990) and 5 of 18 hazardous waste incinerator ash samples at 0.17-41 mg/kg (Carroll and Oberacker 1989). Higher concentrations were detected in bottom ash than in fly ash (Shane et al. 1990).

5.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

The general population is exposed to naphthalene mainly by inhalation of ambient and indoor air. The use of naphthalene-containing moth repellents and smoking are the main sources of naphthalene in indoor air. Other sources include the use of kerosene heaters. Based on an urban/suburban average air concentration of 0.95 $\mu g/m^3$ and an inhalation rate of 20 m^3/day, it has been estimated that the average daily intake from ambient air is 19 ug (Howard 1989). Intake from indoor air may be higher, depending on the presence of indoor sources.

Exposure to methylnaphthalenes is also mainly by inhalation. The estimated average daily intake from ambient air may be about 10 μg for 1-methylnaphthalene and 1 μg for 2-methylnaphthalene. These

estimates are based on ambient air samples taken from 64 (1-methylnaphthalene) and 17 (2-methyl-naphthalene) locations (Shah and Heyerdahl 1988), and an assumed human daily intake of 20 $m^{3.}$

Exposure to naphthalene may occur from ingestion of drinking water and/or food, but these exposures are expected to be much less than inhalation exposures for the general population. Estimated exposure from drinking water, assuming a water concentration range of 0.001-2 μg/L, is 0.002-4 μg/day (Howard 1989). Estimates for food were not calculated.

Accidental ingestion of household products containing naphthalene such as mothballs or deodorant blocks frequently occurs in children. In 1990, 2,400 cases of accidental naphthalene ingestion were reported to 72 Poison Control Centers in the United States (Woolfe et al. 1993). Nearly 90% of these cases occurred in children under 6 years of age.

Dermal exposure to naphthalene may occur from handling or wearing clothing stored in naphthale-necontainingmoth repellents. However, no data were located concerning the level of human exposure to naphthalene, l-methylnaphthalene, or 2-methylnaphthalene via this exposure route. Experimental studies have shown that naphthalene can be dermally absorbed and systemically metabolized in rats (Turkell et al. 1994).

Naphthalene was detected in 40% of human adipose tissue samples at concentrations ranging from less than 9 to 63 μg/kg in a National Human Adipose Tissue Survey (NHATS) (Stanley 1986). Naphthalene was also detected (concentrations not reported) in 6 of 8 selected breast milk samples from women in four U.S. cities (Pellizzari et al. 1982).

Naphthalene exposure may also occur in the workplace. Bjorseth et al. (1978a, 1978b) have reported vapor levels of 1 l-1,100 $\mu g/m^3$ and from 0 (nondetected) to 44 $\mu g/m^3$ for naphthalene particulate in a coke plant. Similar measurements in an aluminum reduction plant yielded somewhat lower levels of 0.72-310 $\mu g/m^3$ for vapor and 0.084 $\mu g/m^3$ for particulates. Higher levels would be anticipated in naphthalene-producing industries and naphthalene-using industries such as wood preserving, tanning, and ink and dye production. A NIOSH (1980) survey of worker exposures to polyaromatic hydrocarbons at a petroleum refinery in Tulsa, Oklahoma reported air concentrations of naphthalene as high as 10.2 $\mu g/m^3$ in an area sample and 19.3 $\mu g/m^3$ for a personal sample. For 2-methylnaphthalene, 17.6 $\mu g/m^3$ was the maximum area concentration reported and 31.9 $\mu g/m^3$ was the highest value for a

personal sample. A National Occupational Exposure Survey (NOES) conducted by NIOSH estimated that 112,702 and 4,358 workers are potentially exposed to naphthalene and 2-methylnaphthalene, respectively (NIOSH 1991). The workers at greatest risk of exposure included mining machine operators, aircraft engine mechanics, and miscellaneous machine operators.

5.6 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

Members of the general population most likely to have high levels of exposure to naphthalene are users of naphthalene-containing moth repellents (including infants exposed to blankets or clothing stored in naphthalene-containing mothballs), smokers, and those in proximity to smokers. Workers in naphthalene-producing or naphthalene-using industries could be subject to heightened exposure, and individuals living or working near hazardous waste sites at which naphthalene has been detected could also be exposed to higher naphthalene concentrations if they came into contact with contaminated media.

5.7 ADEQUACY OF THE DATABASE

Section 104(i)(5) of CERCLA, as amended, directs the Administrator of ATSDR (in consultation with the Administrator of EPA and agencies and programs of the Public Health Service) to assess whether adequate information on the health effects of naphthalene is available. Where adequate information is not available, ATSDR, in conjunction with the NTP, is required to assure the initiation of a program of research designed to determine the health effects (and techniques for developing methods to determine such health effects) of naphthalene.

The following categories of possible data needs have been identified by a joint team of scientists from ATSDR, NTP, and EPA. They are defined as substance-specific informational needs that if met would reduce the uncertainties of human health assessment. This definition should not be interpreted to mean that all data needs discussed in this section must be filled. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

5.7.1 Identification of Data Needs

Physical and Chemical Properties. The physical and chemical properties of naphthalene that are required to evaluate its behavior in the environment have been determined (HSDB 1995; Mabey et al. 1982). Information that documented the physical and chemical properties of 1-methylnaphthalene and 2-methylnaphthalene are also available (HSDB 1995). However, measured values of Henry's law constants and log K_{oc} for methylnaphthalenes would allow more accurate prediction of environmental fate processes.

Production, Import/Export, Use, Release, and Disposal. Naphthalene producers, production locations and volumes, uses, releases, and disposal practices are well documented (CEH 1993; SRI 1992; TRI90 1992). Disposal of naphthalene-containing wastes are regulated by EPA and major spills or accidental releases must be reported to EPA. No data was located on production volume, releases, and disposal practices for 1-methylnaphthalene or 2-methylnaphthalene. This information would be helpful to predict the potential for human exposure to these chemicals.

According to the Emergency Planning and Community Right-to-Know Act of 1986, 42 U.S.C. Section 11023, industries are required to submit substance release and off-site transfer information to the EPA. The Toxics Release Inventory (TRI), which contains this information for 1990, became available in May of 1992. This database is updated yearly and should provide a list of industrial production facilities and emissions.

Environmental Fate. Existing information indicates that most naphthalene is released to the atmosphere and undergoes rapid reaction with hydroxyl radicals (Atkinson et al. 1987; Coons et al. 1982; Howard 1989). Available data indicate that volatilization and biodegradation are important removal processes from water and soil (Coons et al. 1982; Howard 1989; Tabak et al. 1981; Wakeham et al. 1983). Additional studies on the rates of volatilization, degradation, and transport in groundwater would be helpful in assessing potential human exposure in the vicinity of industrial sources and chemical waste sites. Data describing the volatilization, biodegradation, and transport of 1-methylnaphthalene and 2-methylnaphthalene would be useful in predicting the potential for human exposure.

Bioavailability from Environmental Media. No studies were located on the bioavailability of naphthalene in various environmental media. Available toxicity data indicate that naphthalene present in contaminated air and ingested in drinking water or soil is probably absorbed. Confirmatory, quantitative data would be useful. Data on infants indicates that toxicologically significant amounts of naphthalene may be absorbed dermally from residues left on stored clothing, especially under circumstances where baby oil was used on the infants' skin (Schafer 1951). Quantitative studies of the dermal absorption of naphthalene from water and soil would be useful in determining potential exposure for populations living near hazardous waste sites

No data have been located pertaining to the bioavailability of 1-methylnaphthalene or 2-methylnaphthalene in environmental media. Studies in laboratory animals to assess the absorption of this compound via the oral, inhalation, and dermal routes would be useful before bioavailability from each medium can be reasonably estimated.

Food Chain Bioaccumulation. Naphthalene is readily degraded in the environment and is easily metabolized by a wide variety of organisms. These studies indicate that although naphthalene may bioconcentrate to a moderate degree for brief periods it will not significantly bioaccumulate in organisms due to metabolism, and thus, is unlikely to biomagnify through the food chain (Howard 1989; Thomann 1989). Limited data indicate that naphthalene is rarely found in most foods, but may be present in shellfish (Bender and Huggett 1989; Minyard and Roberts 1991). Data were not located on 1-methylnaphthalene and 2-methylnaphthalene levels in foods. Additional data on naphthalene, 1-methylnaphthalene, and 2-methylnaphthalene concentrations in foods would be useful to confirm that human exposure via the foodchain is not significant.

Exposure Levels in Environmental Media. The concentrations of naphthalene in the air, water, and soil have been documented (Howard 1989; Shah and Heyerdahl 1988; Wild et al. 1990; Yu et al. 1990). In addition, indoor air levels have been measured (Chuang et al. 1991; Hung et al. 1992; Wilson et al. 1989). Additional information regarding exposure levels of 1-methylnaphthalene and 2-methylnaphthalene in environmental media would be useful for deriving exposure estimates for the general population.

Reliable monitoring data for the levels of naphthalene in contaminated media at hazardous waste sites are needed so that the information obtained on levels of naphthalene in the environment can be used in

combination with the known body burden of naphthalene to assess the potential risk of adverse health effects in populations living in the vicinity of hazardous waste sites.

Exposure Levels in Humans. A national survey of adipose tissue samples indicates that about 40% of the study subjects had measurable levels of naphthalene (Stanley 1986). Naphthalene was also detected in 6 of 8 samples of human milk (Pellizzari et al. 1982). Data on the effect of cigarette filters on naphthalene uptake by the adipose tissues would be useful.

No data on exposure levels in humans were located for 1-methylnaphthalene or 2-methylnaphthalene. This information would be useful to determine whether any significant exposure to these chemicals occurs

This information is necessary for assessing the need to conduct health studies on these populations.

Exposure Registries. No exposure registries for naphthalene, 1-methylnaphthalene, or 2-methylnaphthalene were located. These substances are not currently listed as compounds for which a subregistry has been established in the National Exposure Registry. These substances will be considered in the future when chemical selection is made for subregistries to be established. The information that is amassed in the National Exposure Registry facilitates the epidemiological research needed to assess adverse health outcomes that may be related to exposure to these substances.

5.7.2 On-going Studies

No on-going studies were located that documented the environmental fate and transport of naphthalene, 1-methylnaphthalene, or 2-methylnaphthalene or on the levels of exposure to these compounds.